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Operations Research in Agriculture: Better Decisions for a Scarce and Uncertain World

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Abstract

Operations Research / Management Science (OR/MS) can be described as the discipline of applying advanced analytical methods to help making better decisions and has been around in the agricultural and forestry management sectors since the fifties, approaching decision problems that range from more strategic sector-level planning to farm operation issues and integrated supply chain management. In this paper insights are given on the use of OR/MS in agriculture, illustrating them with cases drawn from the literature on this topic while keeping the descriptions accessible to uninitiated readers.

The presence of OR/MS in Agriculture and Forest Management applications is already extensive but the potential for development is huge in times where resources are becoming increasingly scarce and more has to be done with less, in a sustainable way.

Key words

Agriculture, Forest Management, Operations Research, Management Science, Decision Support Systems.

Introduction

Although there is no "official" definition for Operations Research/Management Science (OR/MS), it is described at the EURO - The Association of European Operational Research Societies web site (http://www.euro-online.org) as a "scientific approach to the solution of problems in the management of complex systems (...) seeking to facilitate the choice and the implementation of more effective solutions which, typically, may involve complex interactions among people, materials and money.".

An alternative definition can be found at the INFORMS -- The Institute for Operations Research and the Management Sciences - web site (http://www.scienceofbetter.org) devoted to the presentation and dissemination of Operations Research: "Operations research is the discipline of applying advanced analytical methods to help make better decisions.". OR/MS is an active field of research and practice all over the world, with a quite active Latin-American pan-association: "ALIO -- Asociación Latino-Iberoamericana de Investigación Operativa" (http://www-2.dc.uba.ar/alio/).

To try to overcome the lack of a unified definition of this scientific discipline, in Figure 1 we present an illustration of the phases of the OR/MS method, when approaching the resolution of real-world problems.

OR/MS deals with structuring, modelling and solving problems related to decision processes. As an application-oriented scientific discipline, OR/MS practice requires not only interactions with the systems to be tackled but also with the agents that specify, design, build and operate those systems (i.e. with everyone that will have to make decisions, that will act as decision agent). On the other hand, OR/MS is characterized by a rational approach to decision processes, using quantitative methods whenever possible, that encompass a diversified sets of models, techniques and algorithms from different scientific areas, where Mathematics and Informatics play a fundamental role, but from where we cannot discard Sociology and Psychology. On the top of that, all technological application areas are necessarily involved.

In fact, OR/MS has been extensively used in Engineering, Economics, Management, Industry, Public Administration, Services and, of course, in Agriculture and Forest Management. This transversal nature of OR/MS, and its problem solving orientation, makes it a natural tool for every

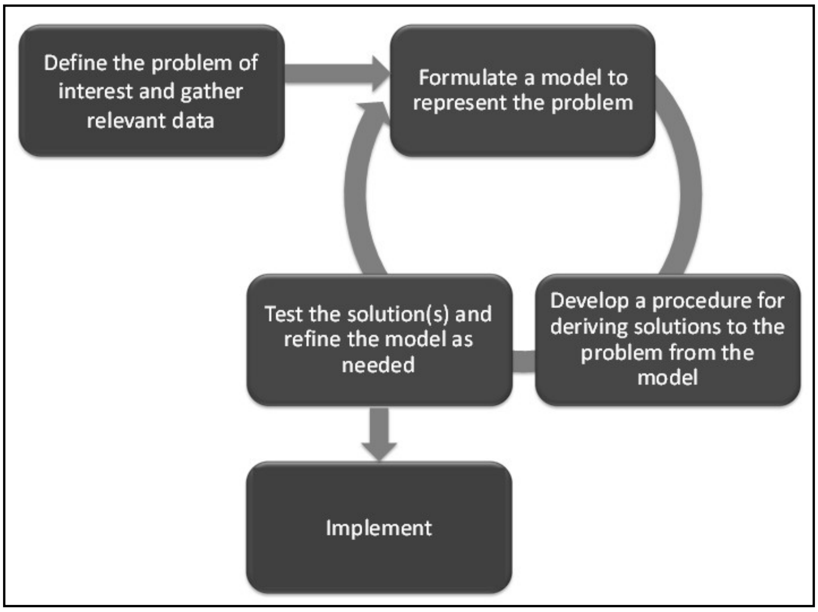

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Figure 1: Phases of the OR/MS method when solving real-world problems.

application area. As we will discuss in this paper, its presence in Agriculture and Forest Management applications is already extensive and the potential for development is huge in times where resources are becoming increasingly scarce and more has to be done with less, in a sustainable way.

In the remaining of the paper we will survey the resources available in the scientific community concerning the application OR/MS in Agriculture and Forest Management, namely conferences, workshops and working groups on the theme. Afterwards, we will review some applications, published in the literature, representative of the planning horizons and scopes that can be addressed, from the more strategic decisions to the operational ones, and from governmental planning to farm running issues. At the same time we will try to offer an insight over the different methodologies and techniques, ranging from risk analysis and uncertainty modelling to performance evaluation or agriculture production optimization.

Materials and methods

In this section we will discuss the resources available from the scientific community.

1. Conferences, Workshops and Streams in conferences

Agriculture is a topic always present in every major OR/MS conference. The largest OR/MS conferences in the world are the EURO Conferences, organized by the OR/MS European Association, the INFORMS Conferences, organized by the North-American society, and the IFORS Conferences, organized by the world federation of OR/MS societies. Looking at the recent past and the near future, we can spot streams of sessions on "OR in Agriculture, Forestry & Natural Resources" and on "OR in Agriculture and Forest Management" in the 2009 EURO Conference, in Bonn and in the 2010 EURO Conference, in Lisbon with a lot of interesting and relevant communications, or a cluster of sessions on "Energy, Natural Resources & the Environment/ Forestry" in the 2010 INFORMS Meeting, in Austin and a similar one at the last CLAIO Conference, in Buenos Aires. In the IFORS 2011 Conference, in Melbourne, a stream on "Forestry Applications" did also run.

However, probably more interesting because more focused, are the specialized meetings. Without trying to be thorough, we may mention a couple of past initiatives that are worthwhile of being followed-up in the future. In the first place, the "EURO Summer Institute 2009 OR in Agriculture and Forest Management", Lleida, Spain, July 25th - August 8th, 2009, where for two weeks young PhD students and senior researchers met to discuss cutting-edge applications of OR/MS in the field. In the United Kingdom, the "OR50: Agriculture and Natural Resources Stream", University of York, September 9th - 11th, 2008. Of high relevance is also the annual meeting organized by the "EURO Working Group on Operational Research (ORin Agriculture and Forest Management (EWG-ORAFM)". However, even in non-specialized congresses we can find important contributions for the field, as in the "International Congress on Modeling and Simulation, Modeling and Simulation Society of Australia and New Zealand - MODSIM 2011" where a session on the impact of climate change on agriculture has been held. Indeed, climate change is a hot topic for agriculture, and once more OR/MS may provide the tools to analyze, model, forecast, simulate and, ultimately, help to make better decisions.

2. Working groups

Another important tool for the scientific development, and consequent improvement of the practice of OR/MS in agriculture, are the "Working Groups".

The "EURO Working Group on OR in Agriculture and Forestry Management (EWG-ORAFM)" aims to encourage communication and research between people with different backgrounds (like industry, university, etc…) who are interested on OR methods and on its application in Agriculture and Forest Management in order to exchange ideas, experiences and research results.

The "OR Society Special Interest Group on Agriculture and Natural Resources (SIG-ANR)", from the United Kingdom Operations Research Society, aims "to encapsulate the management of all of the biotic primary production industries (agriculture, forestry, fisheries, etc…) and their underpinning natural resources (soils, water, ecosystems, etc…), at policy, strategic and tactical levels. This definition includes the production of goods and [ecosystem] services as well as their related chains or webs of secondary industries and logistics. It is application orientated and not restricted to any particular method. (...) The governance and management of these industries place this area at the vanguard of operational research's contribution to sustainability. This Special Interest Group offers a platform for those working on such issues.".

In line with these objectives is the "INFORMS Section on Energy, Natural Resources, and the Environment (ENRE)", organized "to promote the development and application of operations research / management science methods, techniques, and tools to the solution of problems relating to energy, natural resources and/or the environment; encourage the exchange of information among practitioners and users in energy, natural resources, and environmental applications areas; and to promote the maintenance of high professional standards in the application of operations research/ management science to problem areas in energy, natural resources, and/or the environment. (...) ENRE has three strong and active groups: Energy, Forestry and Mining.".

Finally, again in the United Kingdom, the "Natural Resources Management Centre" was established as a result of Cranfield's significant investment in research on natural resources. One of the specific focus of the center is "supporting the practice of urban, rural and agricultural development studies, including sustainable agriculture, rural livelihoods and agri-environmental systems." with a strong contribute on "management of marketing systems, including sustainable supply chain management and its impact on the supply of food, fiber, bio-energy and countryside services, and the sustainable consumption of energy and materials in production and by consumers, and the recovery of waste, especially in the agriculture and food sectors.".

Particularly interesting, as a repository of resources in the field, is the web site "OR4NR Operational Research for the natural resource industries" (http://www.or4nr.interdisciplinary-science.net/).

3. Journals

Scientific results must be validated by the scientific community, and besides conferences, congresses and other meetings, and working groups, the traditional media to spread the acquired knowledge are the scientific journals. It may be said that if we want to know if a scientific area exists and has expression in the scientific community, we should look for the journals on that field. OR/MS and Agriculture and Forest Management passes with distinction that test. Special issues on the topic are regularly published in the top OR/MS journals, as for instance the special volume of "Annals of Operations Research: Operations Research in Forestry" that is edited (chair) by Andrés Weintraub (Universidad de Chile), but also specific journals are published by other scientific publishers.

"Agriculture, Ecosystems & Environment", publicized as an International Journal for Scientific Research on the Interaction Between Agro ecosystems and the Environment, aims at publishing "scientific articles dealing with the interface between agro ecosystems and the natural environment, specifically how agriculture influences the environment and how changes in that environment impact agro ecosystems", with a strong focus on:

- Biological and physical characteristics of agro ecosystems including land, air, and water quality.
- Ecology, diversity and sustainability of agricultural systems.
- Relationships between agro ecosystems and the natural environment.
- Agro ecosystem and global environmental changes including climate change and air pollution.
- Ecological consequences of intensification, soil degradation, waste application, irrigation, and mitigation options.
- Environmental implications of agricultural land use and land use change.

The "Journal of Agricultural Science" publishes papers concerned with the advance of agriculture and the use of land resources throughout the world. It declares as specific topics of interest: "all aspects of crop and animal physiology, modelling of crop and animal systems, the scientific underpinning of agronomy and husbandry, engineering solutions, decision support systems, land use, environmental impacts of agriculture and forestry, impacts of climate change, rural biodiversity, experimental design and statistical analysis, the application of new analytical and study methods (including molecular studies)".

"Agricultural Systems" is an international journal that "deals with interactions - among the components of agricultural systems, among hierarchical levels of agricultural systems, between agricultural and other land use systems, and between agricultural systems and their natural and social environments. (...) Papers generally focus on either methodological approaches to understanding and managing interactions within or among agricultural systems, or the application of holistic or quantitative systems approaches to a range of problems within agricultural systems and their interactions with other systems".

Looking at the declared scope of the journal will help us to introduce the framework under which some examples of published works on OR/MS application to Agriculture and Forest Management will be described in the next section. Topics concerning long term strategic decisions are tackled, when the journal speaks about eco-regional analysis of agriculture and land use, studies on natural resource issues related to agriculture, impact and scenario analyzes related to topics such as genetically modified organisms, multifunctional land use and global change. On the other hand, short and medium-term tactical and operational decisions, concerning producers, farms and local agencies, are dealt with when the journal welcomes contributions on the development and application of systems methodology, including system modelling, simulation and optimization, on approaches to analyzing and improving farming systems, and on technology transfer in tropical and temperate agriculture.

The room for applications of OR/MS methodologies and techniques to agriculture is very large and in the next section a few examples of successful contributions of OR/MS for better decisions in agriculture will be presented.

Results and discussion

In this section we will present some examples of successful applications of OR/MS to problems in agriculture, trying to cover the three levels induced by time scope (strategic, tactical, and operational). These levels are strongly connected to the kind of decision-maker present in the problem. Strategic problems involve usually decisions that have to be made by governments or global financing agencies, while at the operational level decision-makers are usually farm managers, producers or local associations of farmers. Somehow transversal to all time horizons is sustainability. Usually looked at as an environmental issue, involving habitat protection of species, chemical fertilizers abuse or soil protection, it is nowadays tackled together with the economic and social dimensions, originating even more complex systems to analyze and harder decisions to make. Therefore, sustainability is present from the long-term decisions to the day-by-day livestock rations choice. Finally, forestry is for a long time an important OR/MS application sector. In fact what differentiates forest management from the agriculture sector is mainly the time scale, but that is a huge difference. If every day decisions are also present in forest management, even medium-term decisions have impact only dozens of years afterwards, given the time needed to species to grow. Long-term decisions impacts may be measured in a scale of hundreds of years.

Risk and uncertainty have been present in farmer‘s life since ever. Modern man can neither eliminate risk and uncertainty, nor can he control nature, but we are capable of making rational decisions even under scenarios of great uncertainty, controlling and diminishing the risk.

Finally, from the OR/MS toolkit point of view, the selected set of papers is also representative. In some cases the techniques are more normative, by applying optimization models and algorithms, and propose the best decision. Other times, the concept of better decision does not even exist as there are multiple conflicting ways of evaluating a decision, that is, there are decisions that are better for a given criterion and worse for another, and others where the effects are reversed. We resort there to multi-criteria analysis. Other situations exist in which we just need to understand who is performing better. It is not trivial to compare unit's performance when the resources used are not the same, or the intensity with which they are used is dramatically different. Data Envelopment Analysis points the most efficient units by properly trading-off the results with the inputs consumed. Finally, in many circumstances, even the generation and evaluation of several scenarios generation, and there OR/MS can help with Decision Analysis and Simulation.

In the following sections some recent examples on how OR/MS was used to help solving decision problems in agriculture and forestry will be presented.

1. Applications in agriculture at the farm level

Dos Santos et al. (2010) consider a production problem, in which one must meet a known demand of crops while respecting ecologically-based production constraints. The problem has two decision levels. Firstly the division of the available heterogeneous arable areas in plots has to be determined, so that the demand is met, and secondly it is necessary to determine, for each plot, the appropriate crop rotation schedule. Ecological-based constraints, such as the interdiction of certain crop successions, and the regular insertion of fallows and green manures, are considered for the generation of the rotation plans. The problem resolution is modelled by a linear program and solved by means of a column-generation approach. The authors run a set of computational tests using real data of up to 24 crops and report very good performance for this approach.

Still within the optimization framework, Detlefsen and Jensen (2007) also deal with the optimal rotation crop for a given selection of crops on a given piece of land, with sustainability goals. A network modelling approach is followed, proving that special algorithms for solving network problems can be developed and applied to solve the crop rotation problem. This can save computation time and make it tractable to implement crop rotation in whole-farm models. The authors claim that the chosen modelling approach is more strategic than operational, as it does not consider specific fields. One could imagine that the above model came up with a solution that would require part of a field to be grown with one crop and the other part grown with another crop.

A different type of approaches assumes the intrinsically multi-objective nature of these decision problems and tries to deal with it. Hayashi [2000] reviews multi-criteria analysis applied to agricultural resource management. The main goal of the author is to collect, classify and evaluate which criteria are usually used for modelling agricultural systems and to identify the difficulties for practitioners in applying the methodology. As expected, the authors conclude that a multi-criteria analysis brings more expressivity to the problem definition, although it decreases the normative level of the proposed decisions.

Another multi-objective approach is presented by Annetts and Audsley (2002). They consider the problem of identifying the best cropping and machinery options which are both profitable and result in improvements to the environment, depending upon the farm situation of market prices, potential crop yields, soil, and weather characteristics. It is assumed that profit and environment protection are antagonist objectives and therefore a multi-objective optimization model is required. The authors claim that the model is rather flexible, allowing to choose the machinery, timing of operations, crop rotations and levels of inputs and show, for a United Kingdom scenario, that large reductions in environmental impact can be achieved for reductions in farm profit which are insignificant relative to the annual variation due to yields and prices.

Frequently the data that feed the models are not known with precision, either because it has not been collected in the past or because it refers to the future. In both cases, estimations have to be made and used, bringing an additional level of uncertainty to the decision making process. In this context, Biswas and Pal (2005) revisit the land-use planning problem for optimal production of several seasonal crops in a planning year, but describe the utilization of total cultivable land, supply of productive resources, aspiration levels of several crop productions as well as the total expected profit from the farm with fuzzy theory elements. As a case study, the District Nadia region, West Bengal, India is considered. The obtained solution is compared with the existing cropping plan of the District as well as with another solution for the problem, obtained by using previous solution techniques. The authors conclude that the main advantage of the proposed approach is that the decision for proper allocation of cultivable land for production of seasonal crops can be made on the basis of the need to society, even in an environment of uncertainty.

Moschini and Hennessy (2001) also deal with uncertainty and risk. In their paper, the authors address the sources of agricultural risk, production uncertainty, price uncertainty, technological uncertainty and policy uncertainty, and provide an exposition of expected utility theory and of the notion of risk aversion. The article also addresses the agricultural insurance theme, with emphasis on the moral hazard and adverse selection problems that arise in the context of crop insurance.

In line with Moschini and Hennessy, Gómez-Limón [2003] addresses the attitude of farmers when facing risk. It is well known from the literature on multi-criteria decision making the categorization of decision makers in risk-adverse, risk-neutral and risk-seekers. The authors claim that farmers are, in general, risk-adverse decision makers and this characteristic determines their decisions in both the short and long run. In fact, if farmers were risk-neutral, it would be irrelevant to consider risk in their decision-making process, since their responses could be represented by the maximization of the expected profit. However, farmers‘ generalized risk aversion results in decisions that conflict with those that would be regarded as optimal from a social point of view. The authors present a methodology, based on multiple criteria mathematical programming to obtain relative and absolute risk aversion coefficients. Afterwards they apply multi-attribute utility theory to elicit a separable additive multi-attribute utility function and estimate the risk aversion coefficients of farmers of an irrigated area of Northern Spain. The results show a wide variety of attitudes to risk among farmers, who mainly exhibit decreasing absolute risk aversion and constant relative risk aversion. Based on these conclusions agricultural economists try to enhance stabilization features of agricultural policies aimed at reducing farming risk.

2. Applications in agriculture at the sector level

Leaving the farm level, multi-criteria decision-making is still a powerful tool to model situations in which conflicting objectives arise. It is the case described by Van Huylenbroeck (2001) where the impact of policy changes in the behavior and reactions of the farmers is studied. A multi-criteria decision-making methodology is used to analyze shifts in the utility function of farmers. The change from price support to direct income support has decreased the relative importance of the risk objective, while the environmental objective is gaining importance. The multi-objective methodology can be a useful framework for a better understanding of farmers‘ reactions on policy reforms.

When positioning ourselves at the sector level, comparing different farms performance is unavoidable. Farms do not perform equally, and measuring how different are really the performances, discarding all the non-controllable factors, as the size, understanding the reasons for the different performances and determining what should be done to perform as well as the best (benchmark units) is something that Data Envelopment Analysis can help to do. Dhungana et al. (2004) analyze a sample of 76 Nepalese rice farmers, revealing average relative economic, allocative, technical, pure technical and scale inefficiencies of 34, 13, 24, 18 and 7 per cent, respectively. The significant variations in the level of inefficiency across sample farms are attributed to the variations in the `use intensities‘ of resources such as seed, labor, fertilizers and mechanical power. The conclusions of this work show that, operating at best practice, farmers could release resources that could be used to purchase new technologies such as improved seeds, fertilizers and for land improvement.

Another study involving farm efficiency comparison was run in Andalusia, Spain, and is reported by Amores and Contreras (2009). The aim of this study is to help government to define objective criteria to assign European Union (EU) subsidies to olive-growing farms in Andalusia. EU regulations demand objective criteria for the subsidy allocation system and in a sector where more than 60% of the farms would have negative returns without the EU agricultural subsidies, it is difficult to access the real efficiency of the farms. A new Farm Efficiency index is calculated by decomposing overall DEA Scores, by means of internalizing the positive and negative externalities of agricultural activity. The index was tested in a study carried over a sample of 3000 real farms, with data taken from the administrative subsidy database. More important than different decisions concerning the subsidies attribution, the study highlighted areas where there is lack of information to allow proper and grounded decisions.

Also dealing with farm efficiency analysis, Garcá-Alonso et al. (2010) resort to artificial neural network models to compute the farms gross margin, which is a basic element in agrarian programs for sustainable development and directly used by the European Union to assign financial subsidies to the sector. However, the process of farm gross margin determination is complicated and expensive because it is necessary to find the value of all the inputs consumed and outputs produced. With the research described in this paper it was possible to select a representative and reduced set of easy-to-collect descriptive variables to estimate the gross margin of a group of olive-tree farms in Andalusia and validate the best mathematical model obtained for gross margin prediction by analyzing realistic farm and farmer scenarios.

A different OR/MS intervention area, in agriculture, is forecasting. Bhattacharya (2005) develops a pre-harvest forecast of sugarcane yield. The forecast employs a goal programming formulation to estimate the pre-harvest yield of sugarcane on the basis of measurements on biometrical characters of the plant such as plant height, girth of cane, number of canes per plot and width of third leaf from the top. When compared with conventional forecasting methods (regression model using least square technique) this methodology has the advantage of not needing so strong assumptions, allowing, for example, for an estimate of the sugarcane yield 3 months before harvest in situations where the assumptions of conventional regression analysis are violated.

3. Applications in forest management

Decisions on Land use is one of the common applications of OR/MS in forestry planning. Oliveira et al. (1993) tackle an afforestation problem in Denmark, which has the goal of increasing the amount of forest compartments in the country. In this problem there is a set of disjoint potential afforestation areas, areas where actual forest already exist and areas, also disjoint, where afforestation is not recommended. The goal is to locate and design a given number of new forests, with an area equal or bigger than a given value, by merging existing forests and potential afforestation areas, so that the total area where afforestation is not recommended and is included in the new forests, is minimized.

However, as Darek J. Nalle et al. (2004) state, production of marketed commodities and protection of natural systems often conflict and the authors claim their “intent was to continue to bridge the gap between economics and ecology through integration of modelling techniques”. A focus on only one goal can result in large losses in other goals and may result in inefficient and unsustainable outcomes. In this paper the authors develop a dynamic method to evaluate land use decisions and find acceptable alternatives both from the economic and ecological points of view. The method is tested and validated using timber production and species conservation on a forested landscape over a 100-year planning horizon. The results are better than current practice and that a static reserve approach.

Another important OR/MS application area is the forestry supply chain design, planning and operation. The forestry supply chain involves all activities concerning the flow of fiber from the forest to the customer. D’Amours et al. (2008) present an overview of problems arising in this supply chain, ranging from the long-term strategic rotations of forest growth, that can span over more than 80 years, to the very short-term operational problems, as the lumber cutting stock problem, truck routing problems or finished product distribution. In the middle we have tactical planning that deals with the detailed operative planning and closes the gap between the strategic and the operational levels by globally analyzing the supply chain and creating the framework where operations will take place.

Forestry supply chain management and optimization is also the goal of Carlsson and Ronnqvist (2005). Looking at the wood-flow, starting with standing trees in forests, continuing with harvesting, bucking, sorting, transportation to terminals, sawmills, pulp mills, paper mills and heating plants, conversion into products such as pulp, paper, lumber, and ending at different customers, the authors conclude that many planning problems arise, over different time horizons, whose coordination is vital for the companies in the sector. Another important remark of these authors is that there is a systematic and endemic lack of data that prevents a better exploitation of the techniques that OR/MS has to offer to the sector.

However, more operational problems are also dealt with in forestry management, and solved by optimization techniques. Gunnarsson et al. (2004) propose a mixed integer linear programming model to decide when and where forest residues are to be converted into forest fuel, and how the residues are to be transported and stored in order to satisfy demand at heating plants. Additionally, decisions include whether or not additional harvest areas and saw-mills are to be contracted. In parallel they consider the flow of products from saw-mills and import harbors, and decide which terminals to use. The solution approach is tested with data from a large Swedish supplying company.

4. Surveys and overviews

In the previous sections we have tried to point out some recent applications of OR/MS techniques to agricultural and forestry problems, with the objective of being illustrative but not exhaustive. However, very good surveys and overviews on this area have been published. The first survey we would like to refer to is authored by Andrés Weintraub, from the Department of Industrial Engineering of the University of Chile, which, together with Mikael Rönnqvist from the Department of Finance and Management Science of the Norwegian School of Economics and Business Administration, are two of the most prominent researchers on applications of OR/MS to agriculture and forest management. Weintraub and Romero (2006) analyze the use of OR/MS to assess the past performance of its models in this field and to highlight current problems and future directions of research and applications. They divide the agriculture planning problems into farm level and regional-sector level and go through the application of several OR/MS techniques. In what concerns forestry planning the division is on strategic, tactical and operational levels and, once again, the authors go through the application of several techniques to problems of each one of the levels, pointing out the increasing importance of environmental issues. In terms of trends, dealing with uncertainty and risk are definitely the next big challenges for the sector. In the forestry sector, planning and operating the supply chain as a whole will be the tendency for the next years. Audsley and Sandars (2009) go through a similar survey, with as focus on the United Kingdom and with an insight on the need of an holistic approach to the problems of the sector.

Especially interesting is also the book edited by Romero and Rehman (2003). In the first part of the book the MCDM approach is introduced and discussed, while in the second part more advanced topics are presented, including techniques to deal with uncertainty and risk. The third and final part of the book presents three very interesting case studies. The first one is about the evaluation of the agrarian reform program in Andalusia, Spain, the second addresses the livestock ration problem and the final case is about a diet problem for cattle.

Conclusions

In this paper we have tried to give an overview of the potential of application of OR/MS to agricultural and forestry decision problems. As stated in Weintraub and Romero (2006), “Agriculture is one of the fields in which OR models were first used and have been most widely applied.” To the best of our knowledge, the first paper with an application of OR to agriculture was published in 1954 (Heady, 1954) in the Journal of Farm Economics, where Earl Heady demonstrates the use of linear programming for land allocation on crop planning problems. Nowadays the OR/MS community devoted to agricultural decision problems is big and quite active, with an increase on the use of OR/MS models, mainly because of the development of personal commercial software programs (Weintraub and Romero, 2006).

The future is even more promising, as scarce resources and environmental pressures will demand for better decisions that should be technically better grounded and better explained. Because we have only one world to feed an increasing number of people, and fertile land is limited and scarce, Operations Research / Management Science will be in a near future a fundamental science for everyone needing to make decisions in the agricultural sector.

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